Megaparsec scale structures in clusters

The Mpc radio arcs in Abell 3376

The Mpc filament in Abell 85

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Mpc radio arcs in Abell 3376

Collaborators

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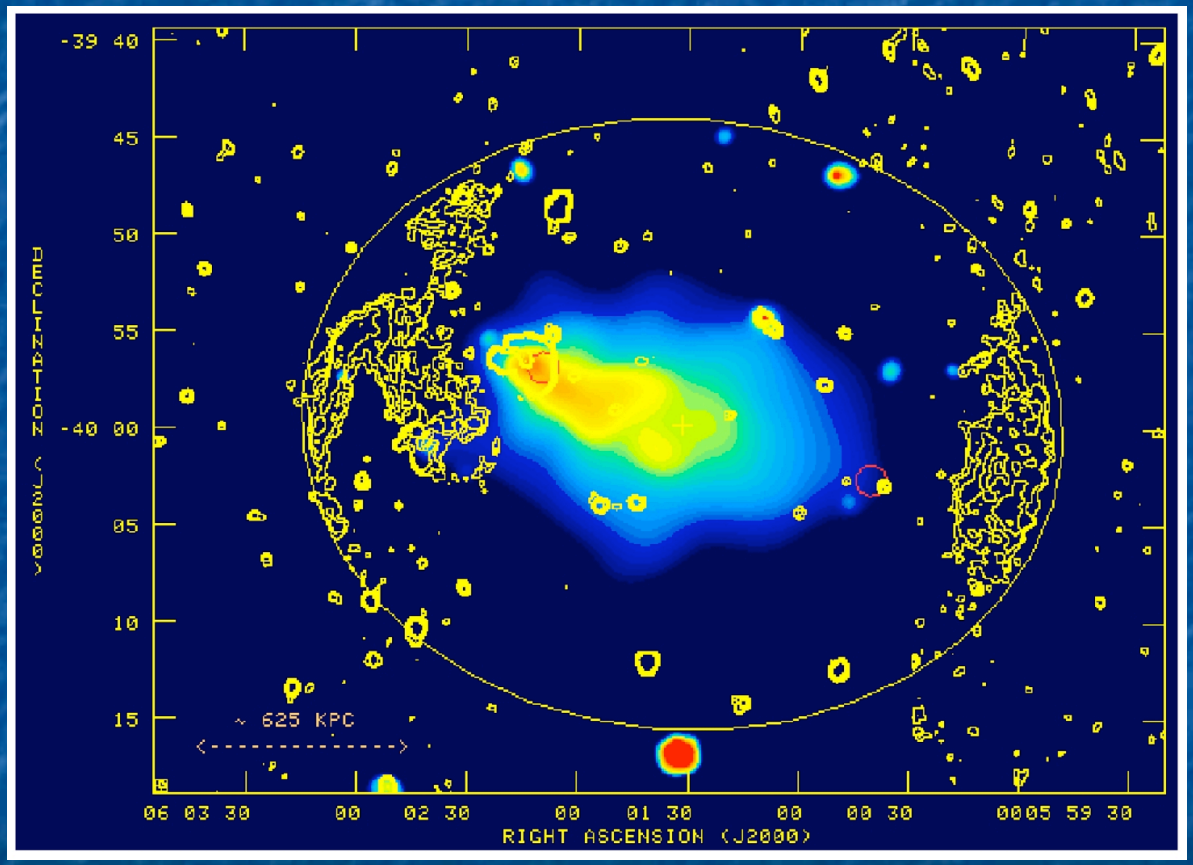
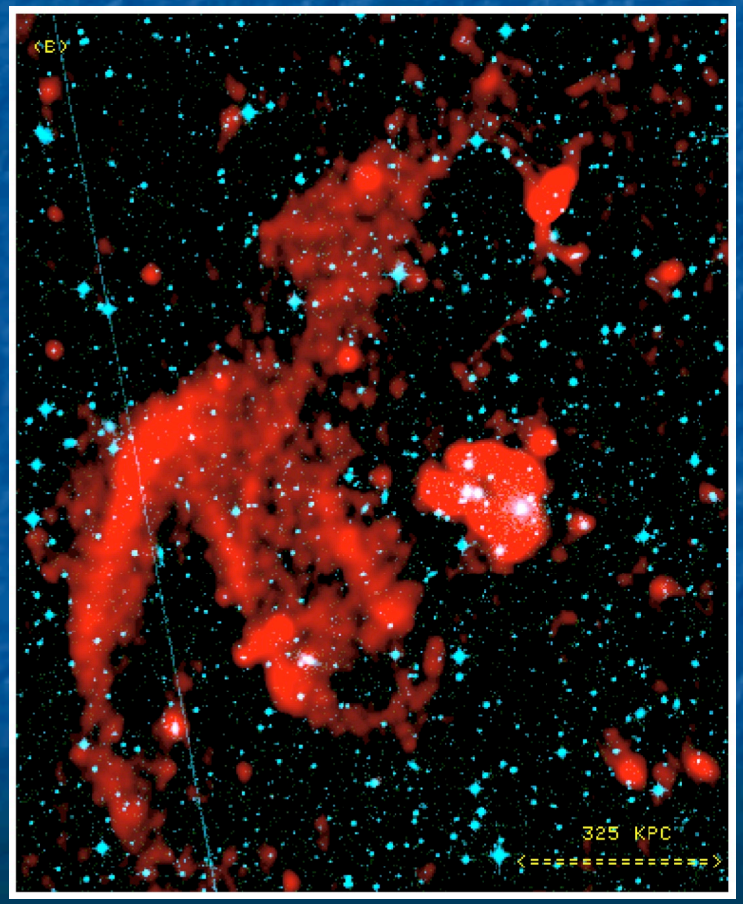
The Mpc radio arcs in Abell 3376 (z=0.046)

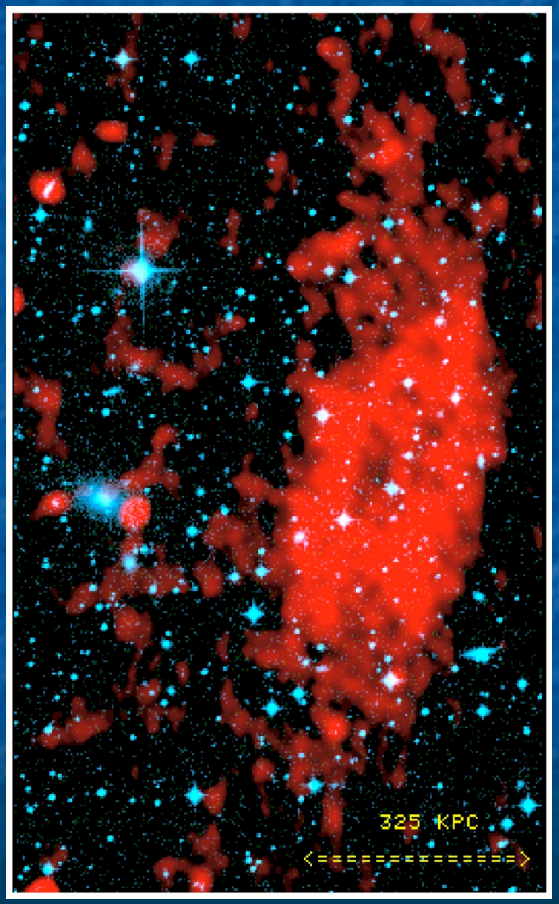


Smoothed ROSAT X-ray image and radio contours (VLA, 20cm)

Bagchi, Durret, Lima Neto & Paul 2006, Science 314, 791

A zoom on the radio arcs





A few characteristics of Abell 3376

- 2 Mpc diameter radio arcs detected with the VLA at 20 cm, no optical or X-ray counterparts (ROSAT or XMM)
- Elongated X-ray emission (ROSAT, XMM-Newton)

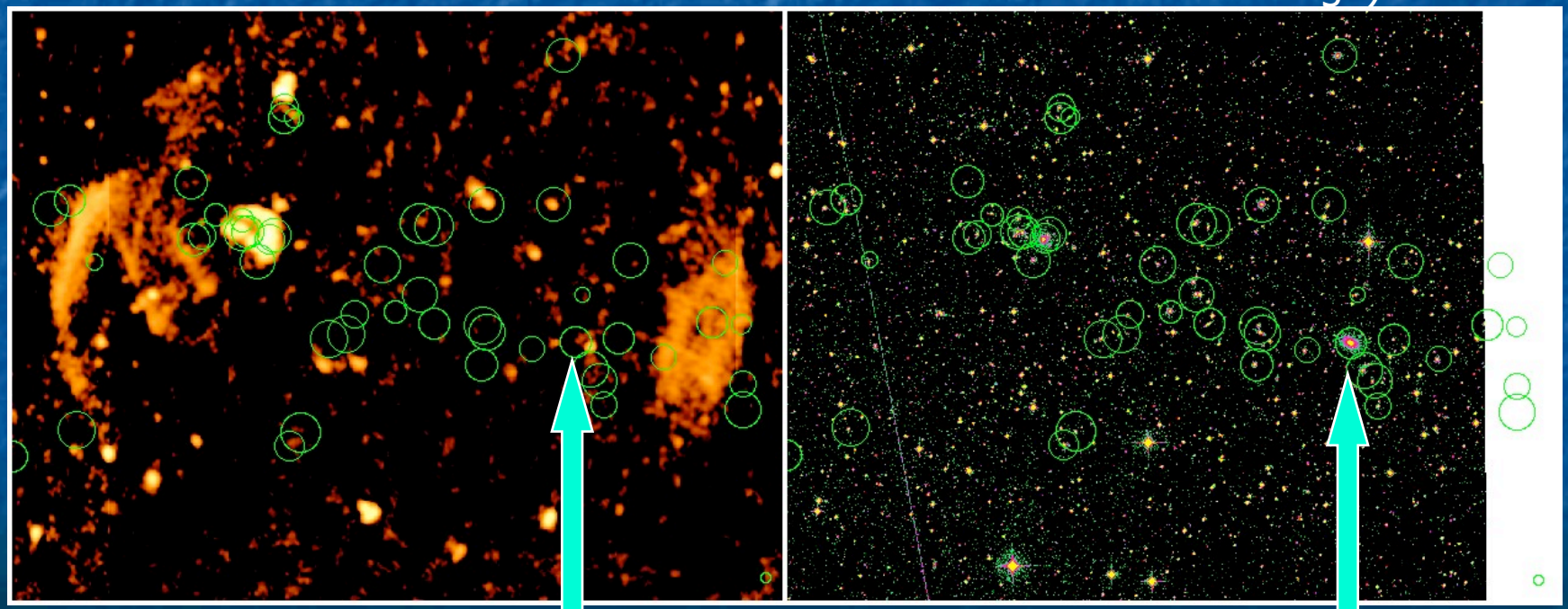
Where do these radio arcs come from?

- Radio synchrotron emission requires accelerated electrons
- Distribution on an ellipse with major axis along direction of X-ray elongation
- Two possibilities:
  - Major cluster merger(s)
  - Cosmological shock waves caused by energetic collisions, mergers and infall on the cluster during the cluster formation

Abell 3376 at other wavelengths
Optical: completely offcentered BCG galaxy

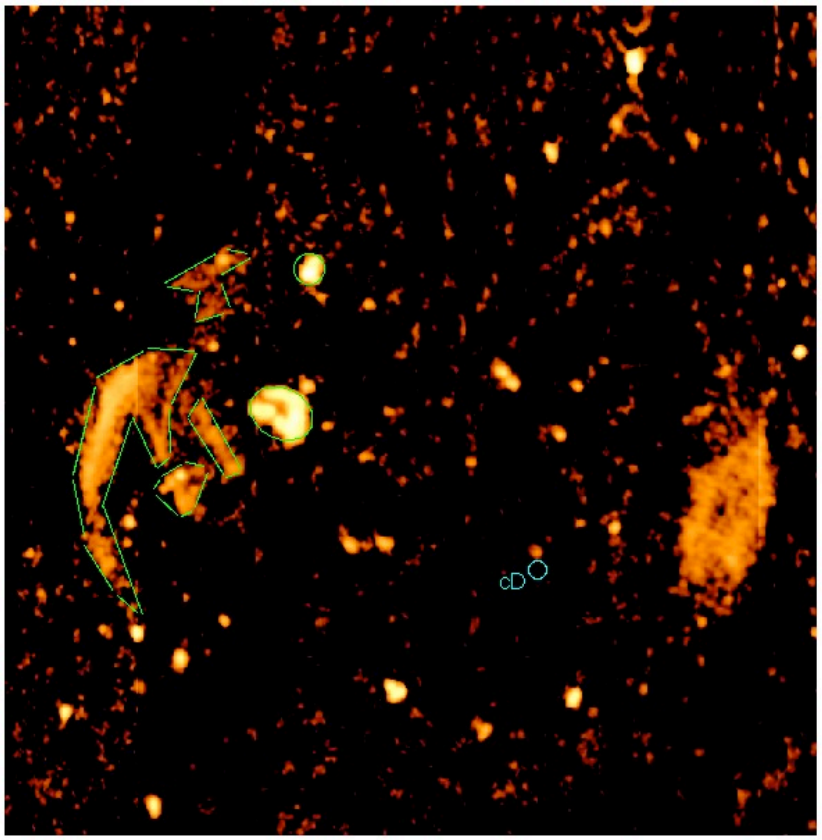
Radio map:
strong bent source and
two faint extended relics

DSS optical image
(circles=galaxies with redshifts
in the cluster range)



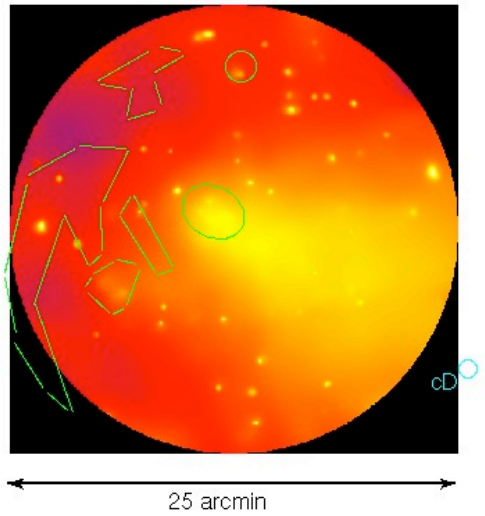
- Maximum of X-ray emission coincides with strong radio source
- This region (green ellipse) contains at least 5 AGN (Chandra)
- No relation between east radio relic and X-ray emission
- No radio or X-ray emission from cD galaxy

Radio map

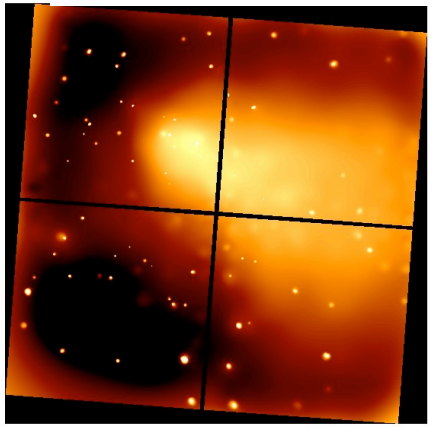


Smoothed X-ray images

XMM-Newton

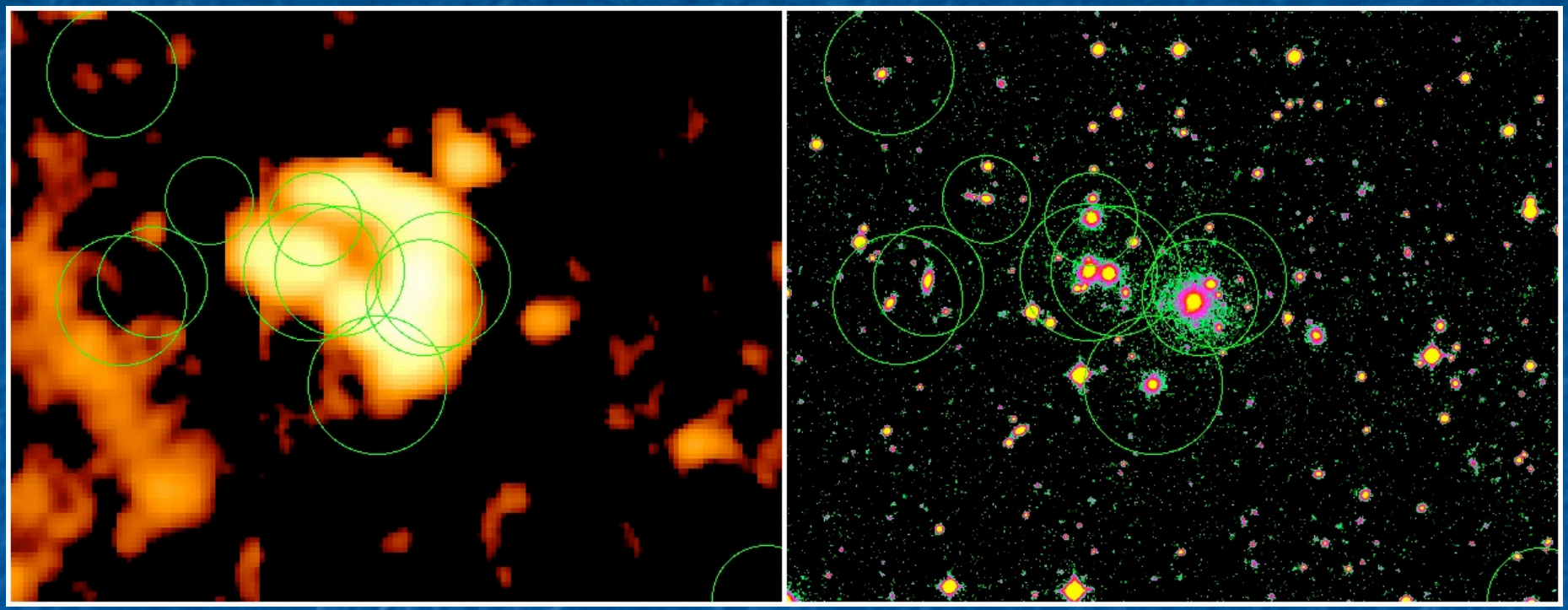


Chandra



Zoom of strong radio source

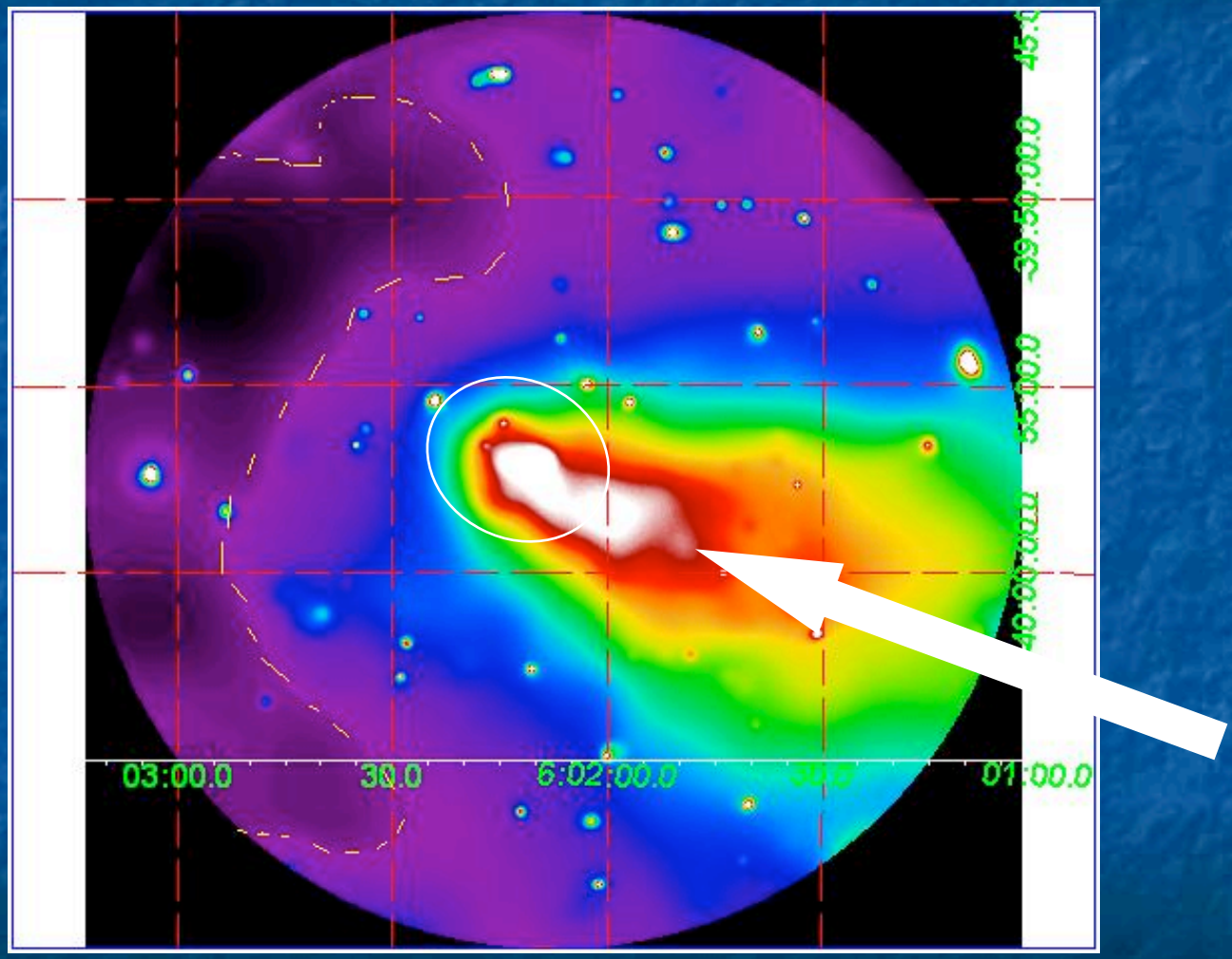
DSS optical counterpart



Radio map could suggest a movement towards the SW

Radio emission can also be the superposition of individual radio sources

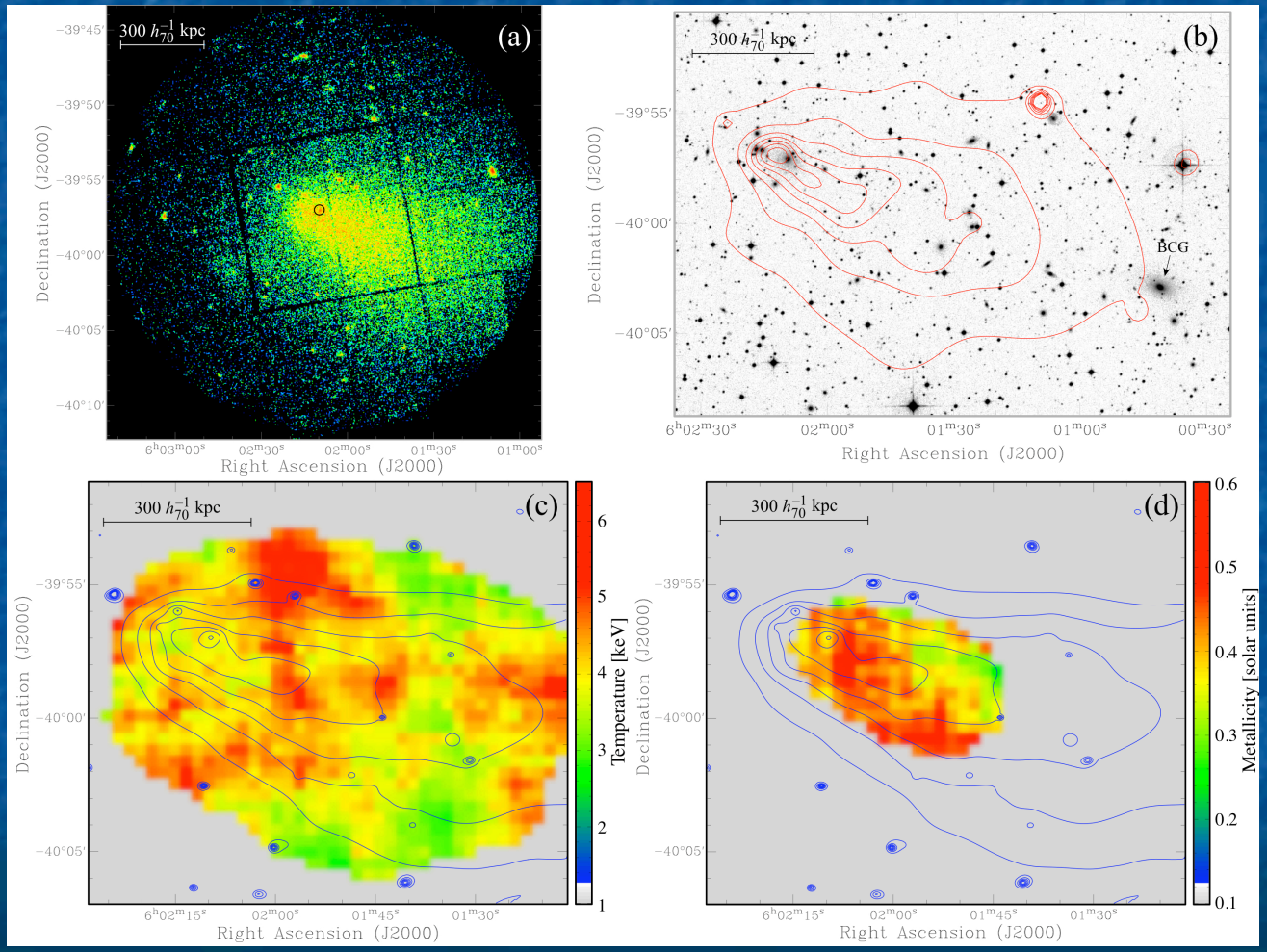
Merging hypothesis: a cluster has crossed the main cluster from SW and got stripped



Smoothed XMM-Newton image

Abell 3376 maps

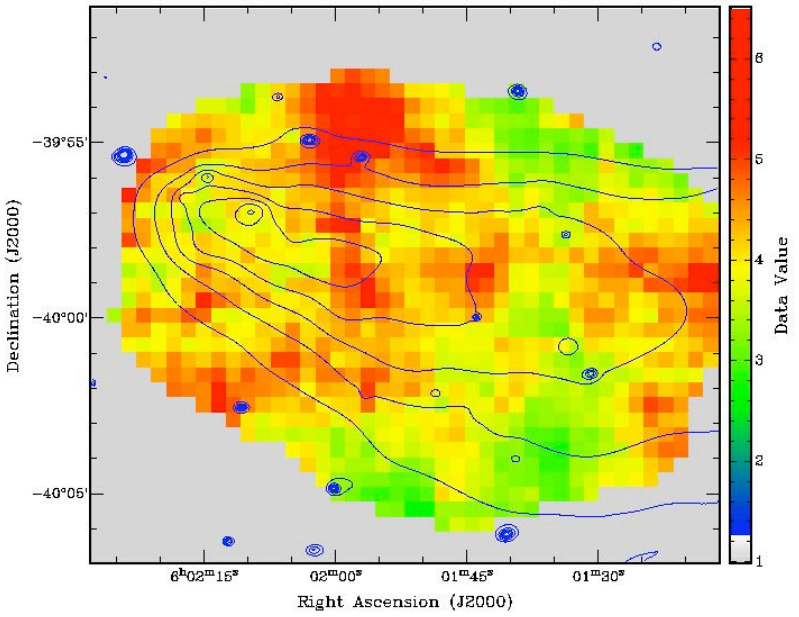
X-rays (ROSAT)



Optical image

X-ray temperature map (XMM)

X-ray metallicity map (XMM)



Temperature map

Comparison with numerical simulations (Takizawa 2005, ApJ 629, 791)

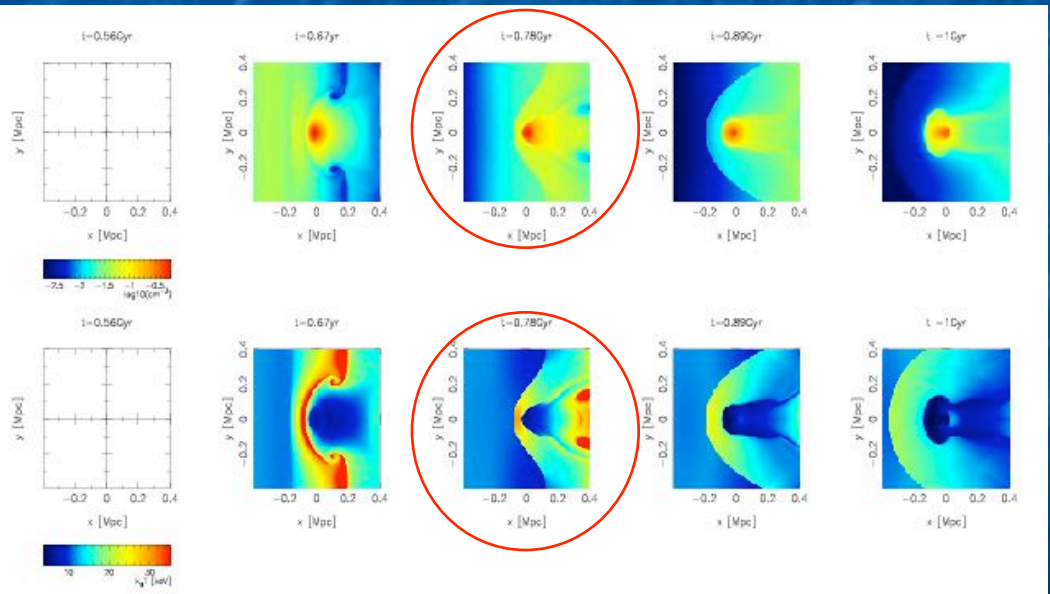
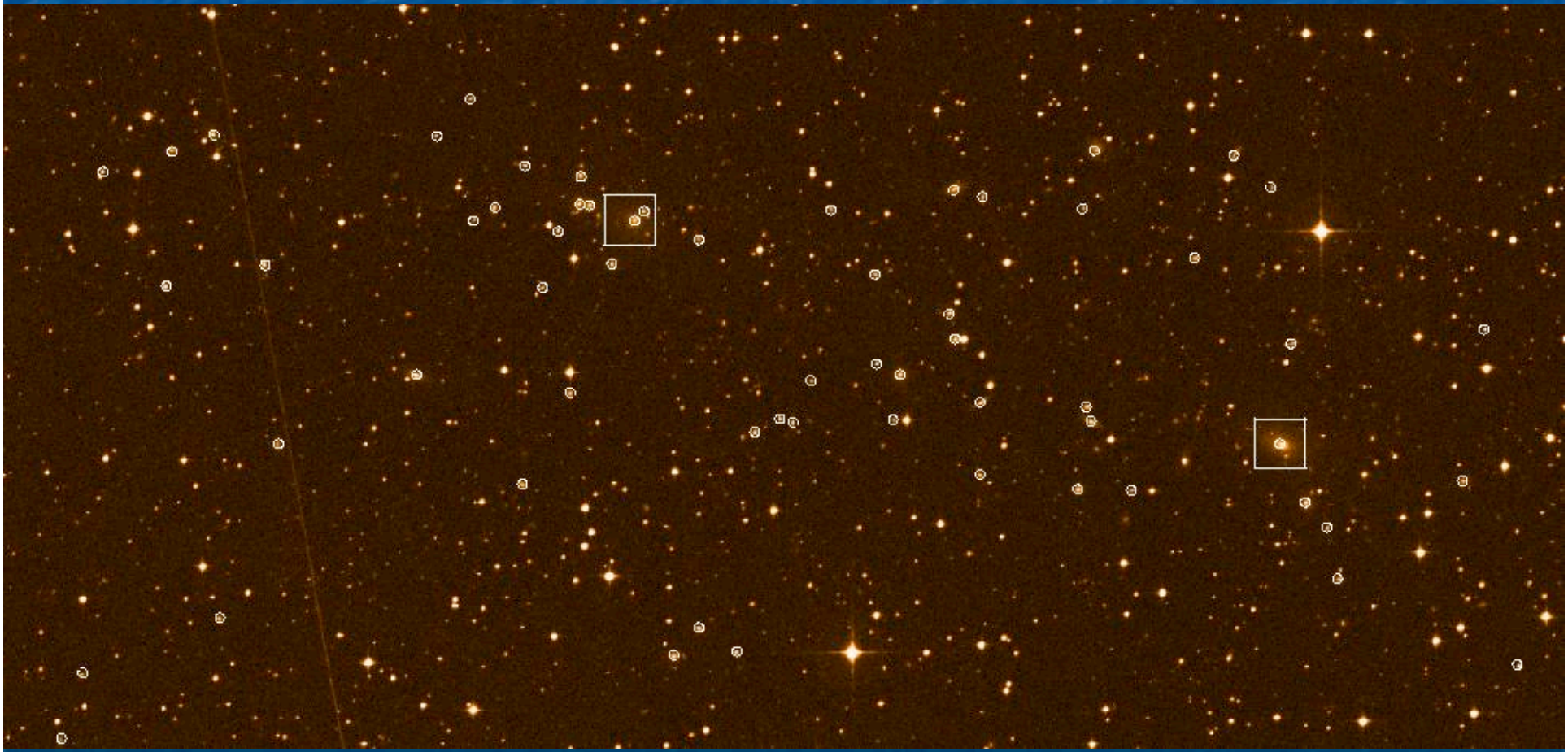


Fig. 3.— Upper panels show snapshots of the density distribution on the $z = 0$ surface at $t = 0.56$, 0.67, 0.78, 0.89, and 1.0 Gyr of the radial infall model. Lower panels show the same ones but for the temperature distribution.

What do these maps tell us?

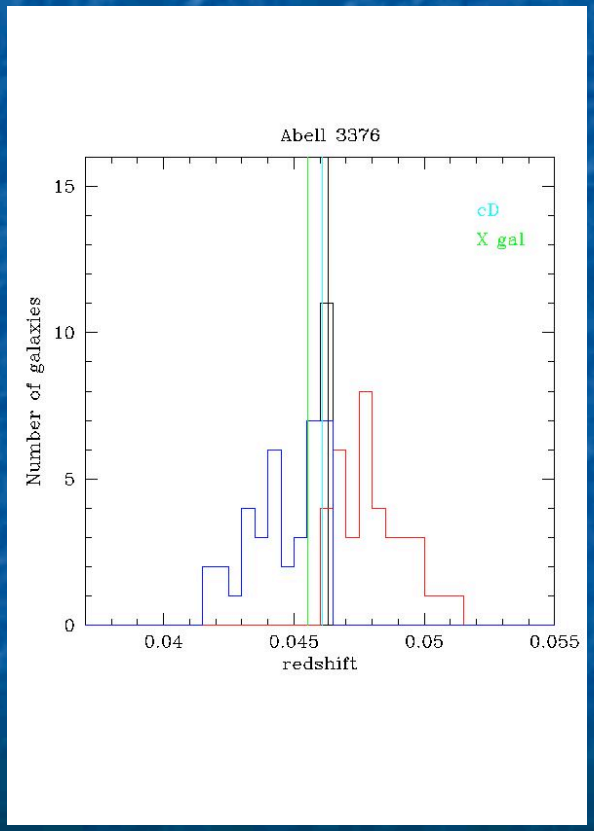
- Optical: the brightest cluster galaxy is completely offset towards the SW
- There is a group of bright galaxies coinciding with the region of maximum X-ray emission
- X-ray temperature map shows alternatively hotter and cooler gas
- X-ray metallicity map shows inhomogeneous metal distribution

Bright galaxies aligned along a filament?
Orientation of filament agrees with direction of merging

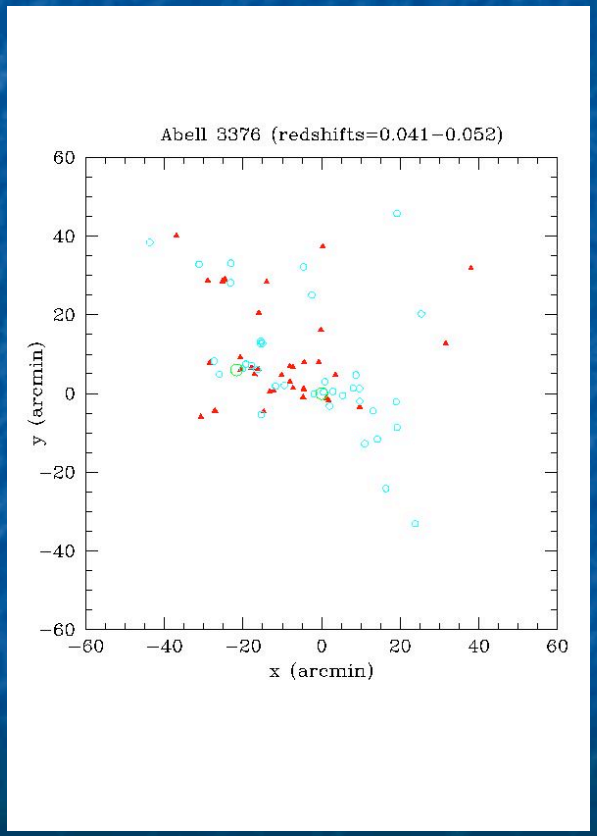


Galaxy positions and movements: the merger takes place in the plane of the sky

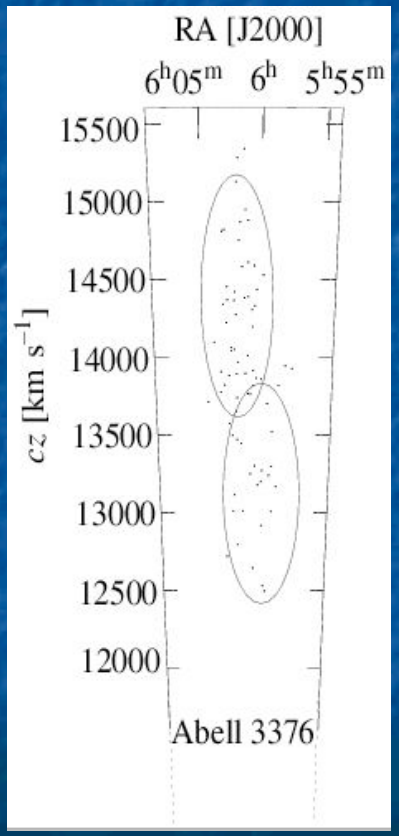
Redshift histogram



Positions of galaxies with redshifts in the cluster



Wedge diagram



Tentative interpretation

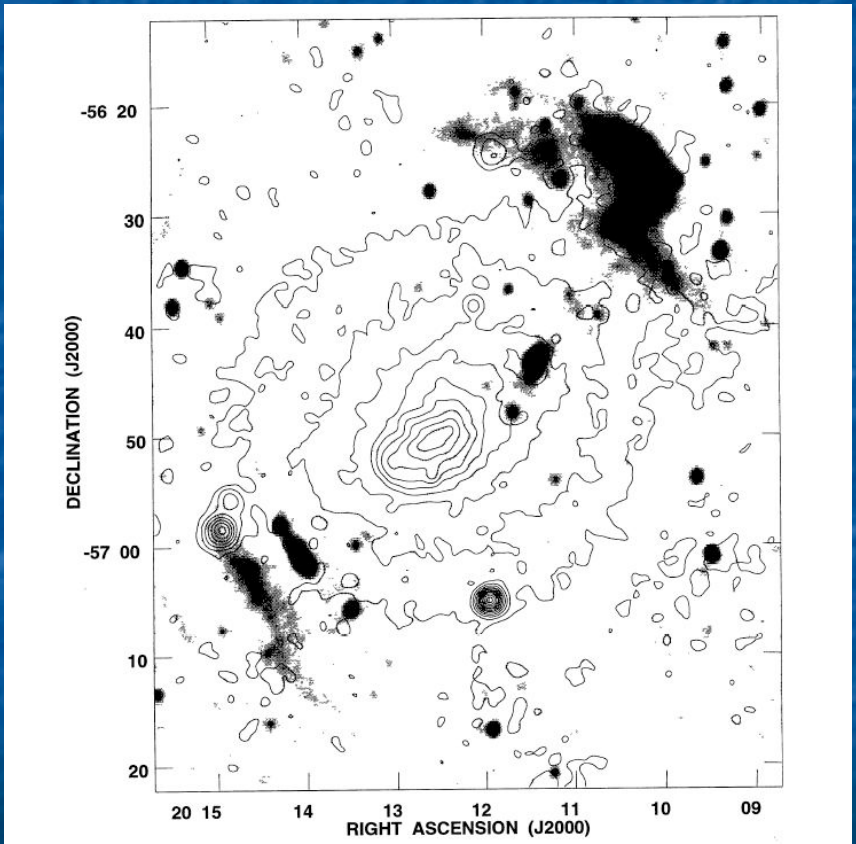
- At least one merging episode is taking place, coming from the SW
- Previous merging episodes may have taken place, accounting for the electron acceleration by shocks in the Mpc scale radio arcs
- Alternatively, the electrons may have been accelerated by cosmological shock waves during the formation of the cluster

Comparison with possibly similar clusters

Abell 3667

ROSAT X-ray contours: elongated structure suggesting a previous merger

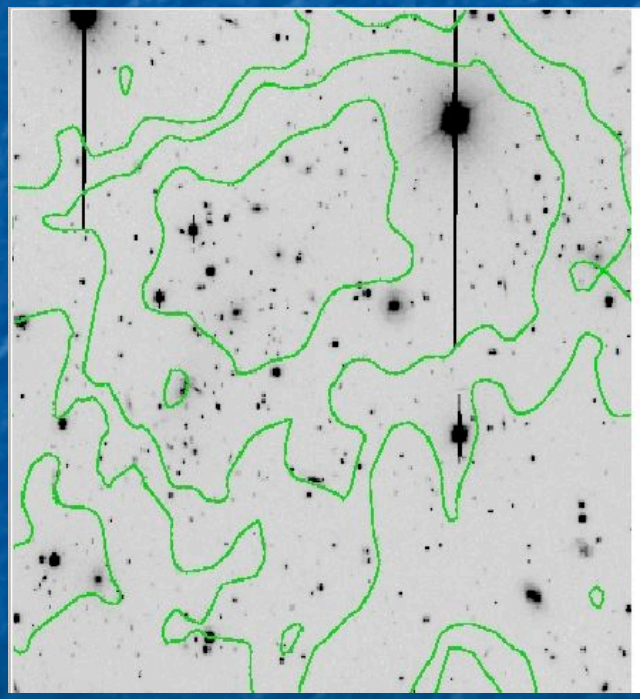
Radio map: extended emission on either side of the X-ray elongation



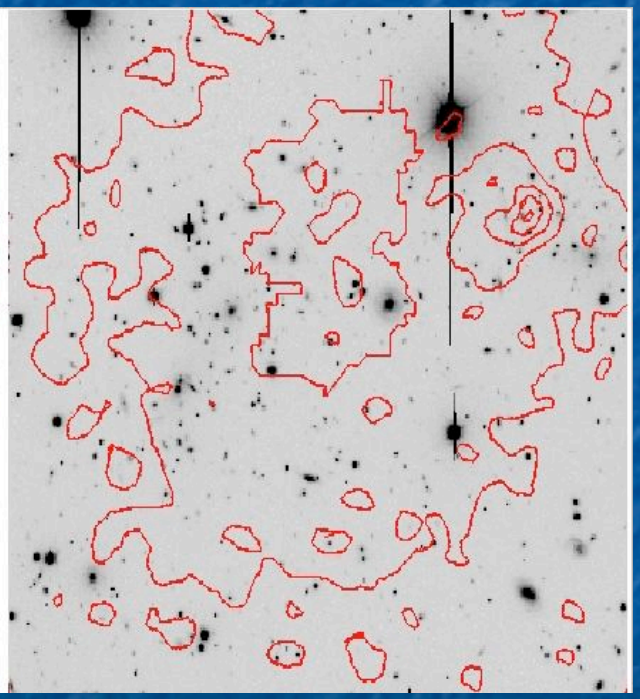
Röttgering et al. 1997, MNRAS 290, 577

The « bullet » cluster 1E0657-56: a small cluster has crossed another cluster

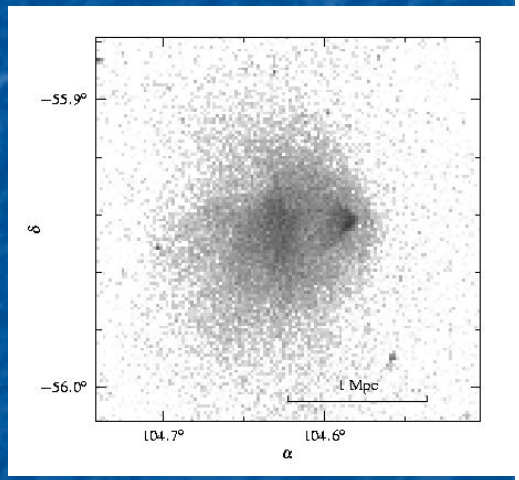
Radio 1.3GHz + optical image



ROSAT X-rays + optical image



Chandra X-rays



Barrena et al. 2002, A&A 386, 816; Markevitch et al. 2002, ApJ 567, L27

A model for the bullet cluster

- Simulation of substructure propagation of a small cluster in a larger one, taking into account the tidal force
- Calculate the positions of the X-ray substructure and of its corresponding dark halo as a function of time, and other quantities (Mach number of the merger shock)
- Could be applied to Abell 3376

Prokhorov & Durret 2007, A&A 474, 375

The 4 Mpc filament in Abell 85 at X-ray and optical wavelengths

Collaborators

X-rays

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William Forman (CfA, USA)
Eugene Churazov (MPE, Garching)

Optical

Gwenaël Boué, Gary Mamon (IAP)
Christophe Adami, Olivier Ilbert (LAM, France)
Véronique Cayatte (Luth, France)

Do clusters remember how they formed?

- Numerical simulations predict that clusters form at the intersection of filaments
- Preferential orientation at all scales:
  - central galaxy
  - brightest galaxies
  - overall galaxy distribution
  - X-ray gas distribution
- Abell 85 shows preferential orientations at all these scales

  X-ray filament detected by ROSAT (PSPC) and confirmed by XMM-Newton

X-ray filaments

- When ROSAT all sky survey background fluctuations were correlated with Abell cluster catalogue, no filament was detected

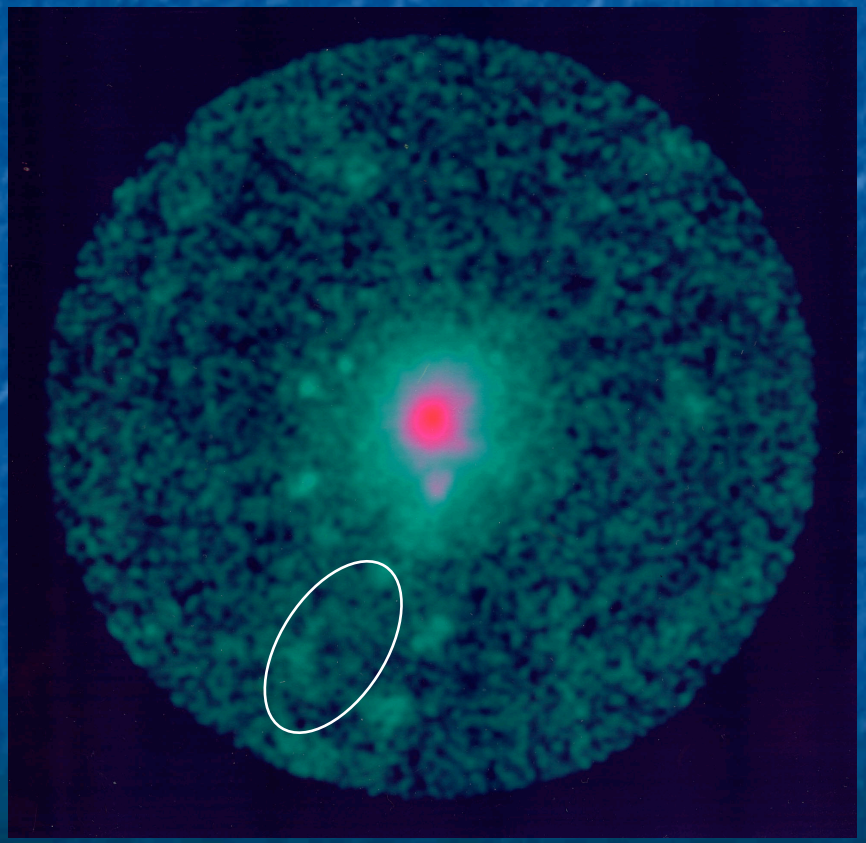
X-ray filaments are rare and/or weak

Prediction: $n_e < (7.4\ 10^{-5} – 1.4\ 10^{-4})\ h_{100}^{-1/2}\ cm^{-3}$
in agreement with hydro simulations

(Briel & Henry 1995, A&A 302, L9)

The X-ray filament in Abell 85

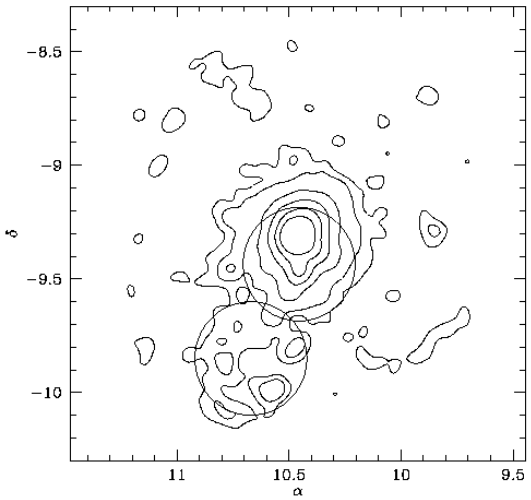
Discovery with the ROSAT PSPC



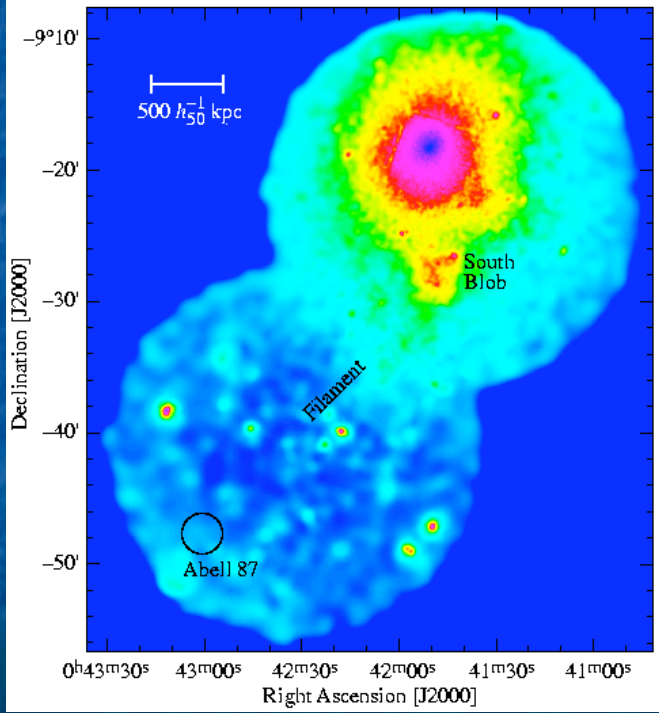
(Durret, Forman, Gerbal, Jones & Vikhlinin 1998, A&A 335, 41)

Confirmation with XMM-Newton

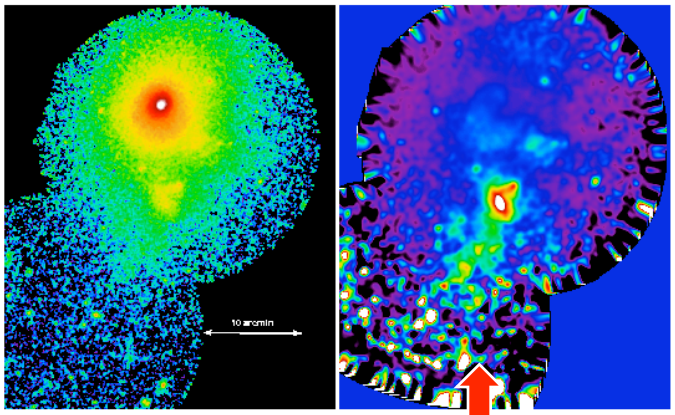
The two XMM pointings superimposed on ROSAT contours



XMM raw data

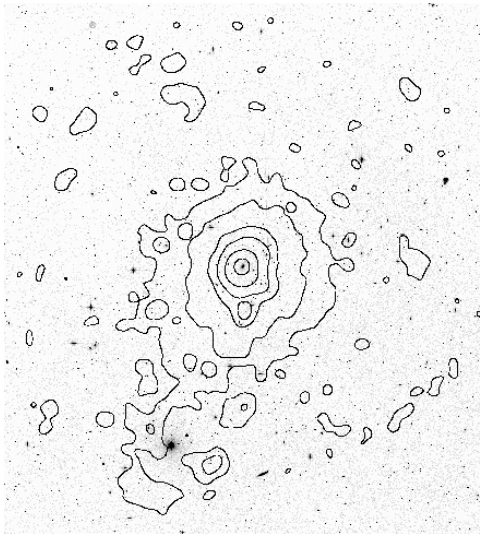


XMM-Newton



The filament after subtraction of an azimuthally averaged model

ROSAT contours



Results

X-ray temperature, metallicity and luminosity of the filament:

$2 \text{ keV} < kT < 2.8 \text{ keV}$

$0.04 < Z < 0.33\ Z_{solar}$

L_X (2-10 keV)= $5.2\ 10^{42}\ h_{50}^{-2}$ erg s^{-1}

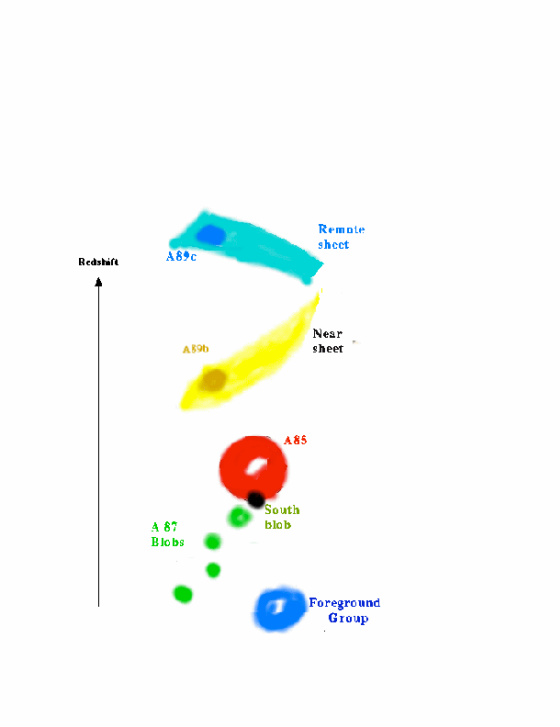
(MEKAL model, N_H fixed)

Values typical of groups, though temperature is rather high

(Durret, Lima-Neto, Forman & Churazov 2003, A&A 404, L29)

The « filament » was interpreted as made of groups falling onto the cluster

The optical view



Daniel Gerbal's artist view of the Abell 85/87/89 complex

- A « filament » (Abell 87) falls onto the main cluster (Abell 85)
- The impact region is just north of the South blob
- The X-ray gas is compressed in the impact zone and hotter. There are also more emission line galaxies in this region
- There should be a concentration of galaxies and more star forming galaxies in the filament

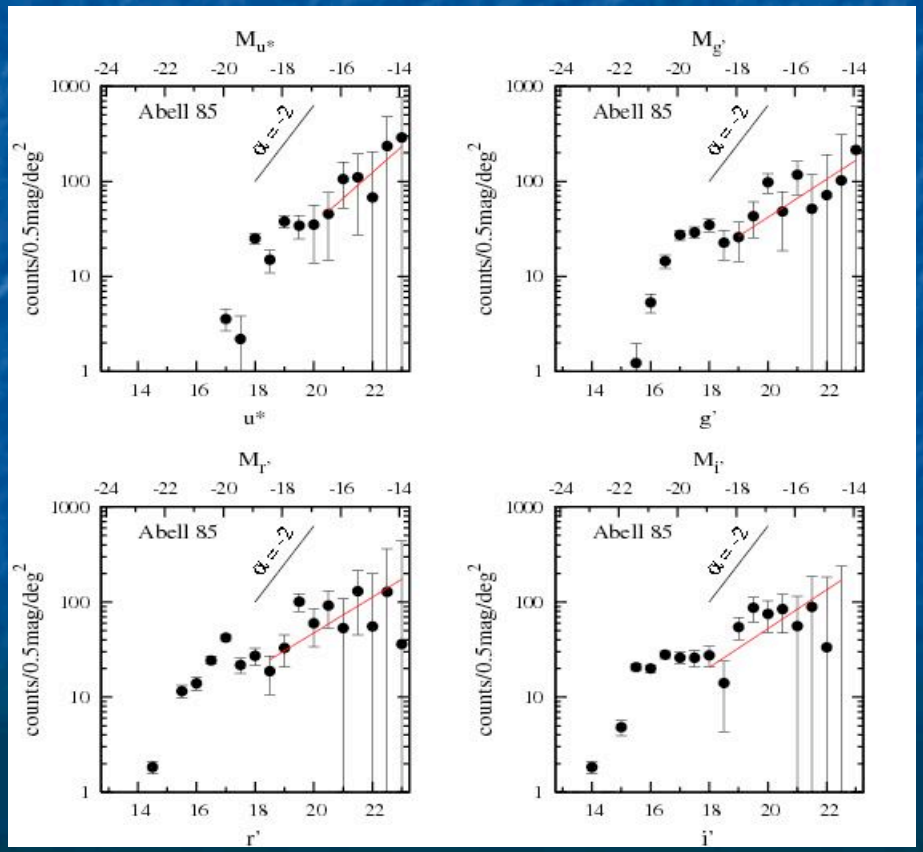
New optical data on the Abell 85 filament

- Deep u* g′ r′ i′ imaging with CFHT Megacam (1°x1° field)
- Halpha and R imaging with ESO 2.2m WFI (38′x36′ field)

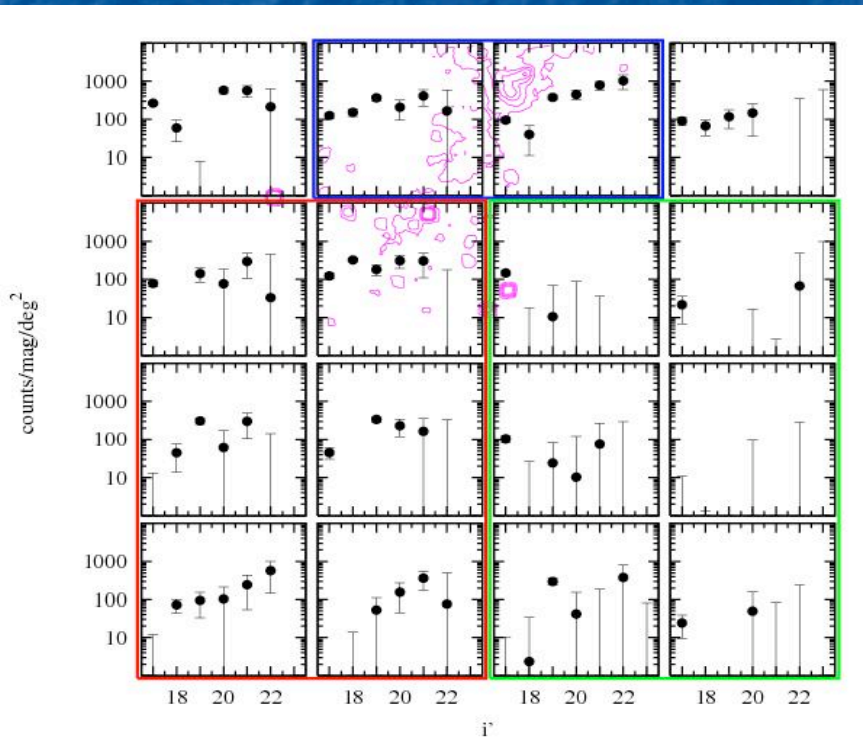
(Boué, Durret, Adami, Mamon, Ilbert & Cayatte 2008, A&A submitted)

Galaxy luminosity functions (GLFs) in the filament region

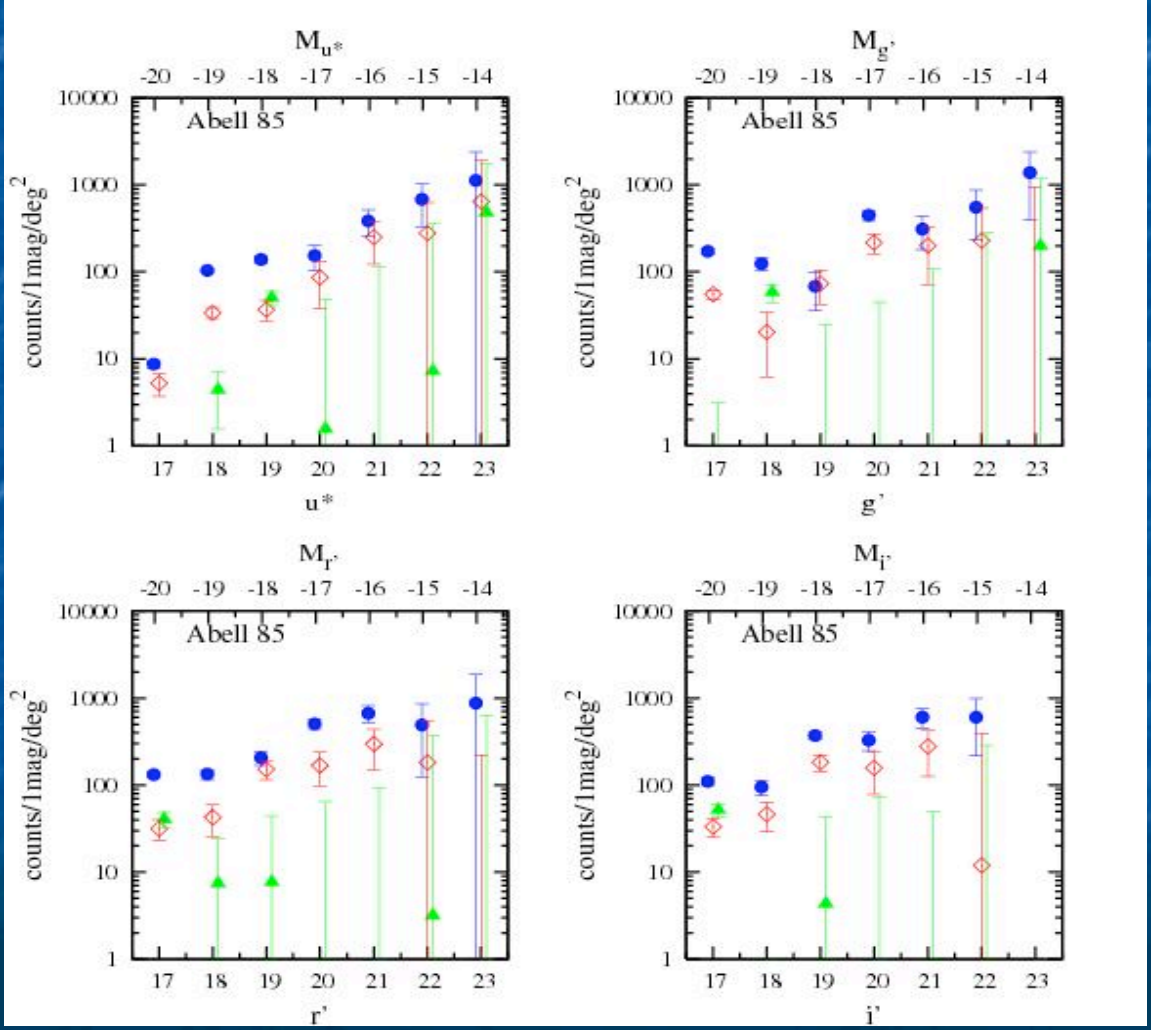
Global GLFs in the four bands



GLFs in 16 squares in the i' band



GLFs in the 3 main regions in the i' band

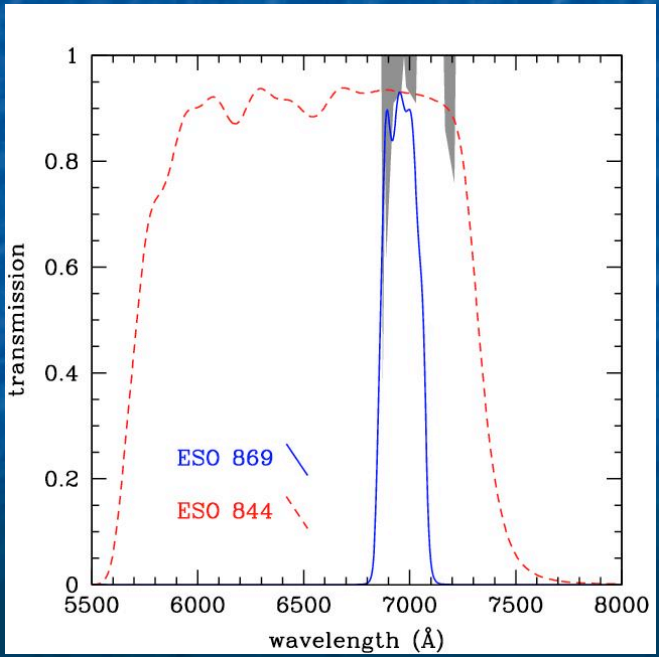


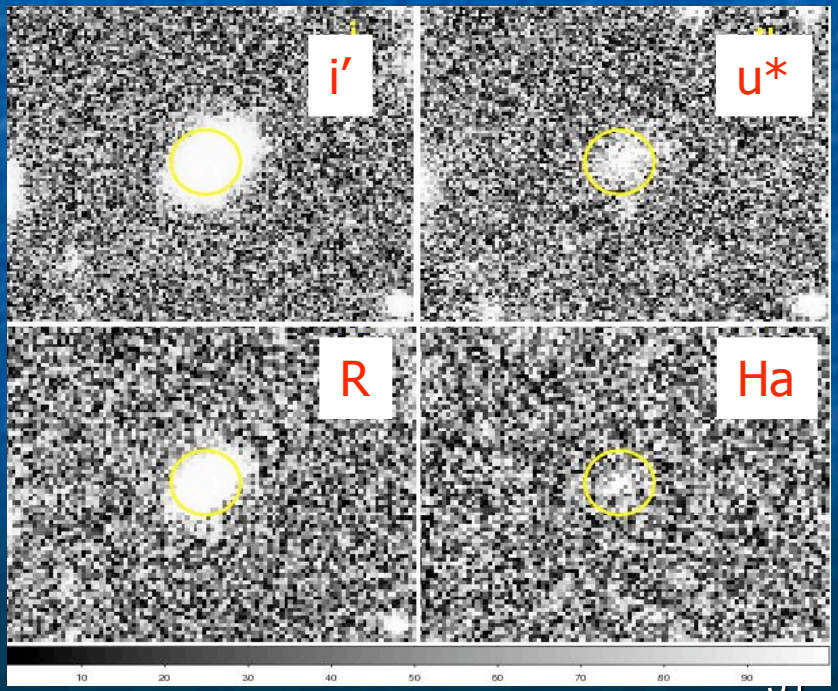
The red region is quite densely populated, while there are hardly any galaxies in the green region

There is a clear galaxy excess in the filament relative to the field

Halpha imaging

- 101 galaxies detected in Halpha image
- But continuum subtraction is tricky!
- And filter cut +telluric absorption!



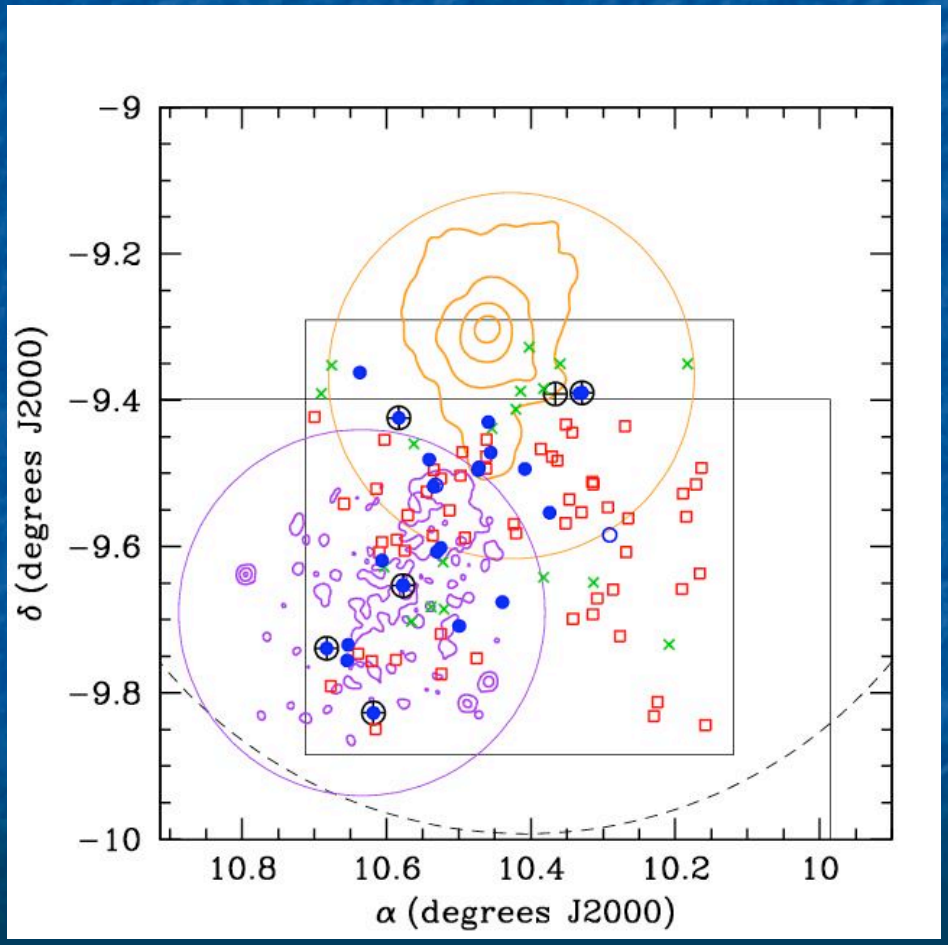


Are the galaxies detected in Halpha members of the filament?

- 23 have redshifts in the cluster
- 2 have redshifts outside the cluster
- 58 galaxies have photometric redshifts

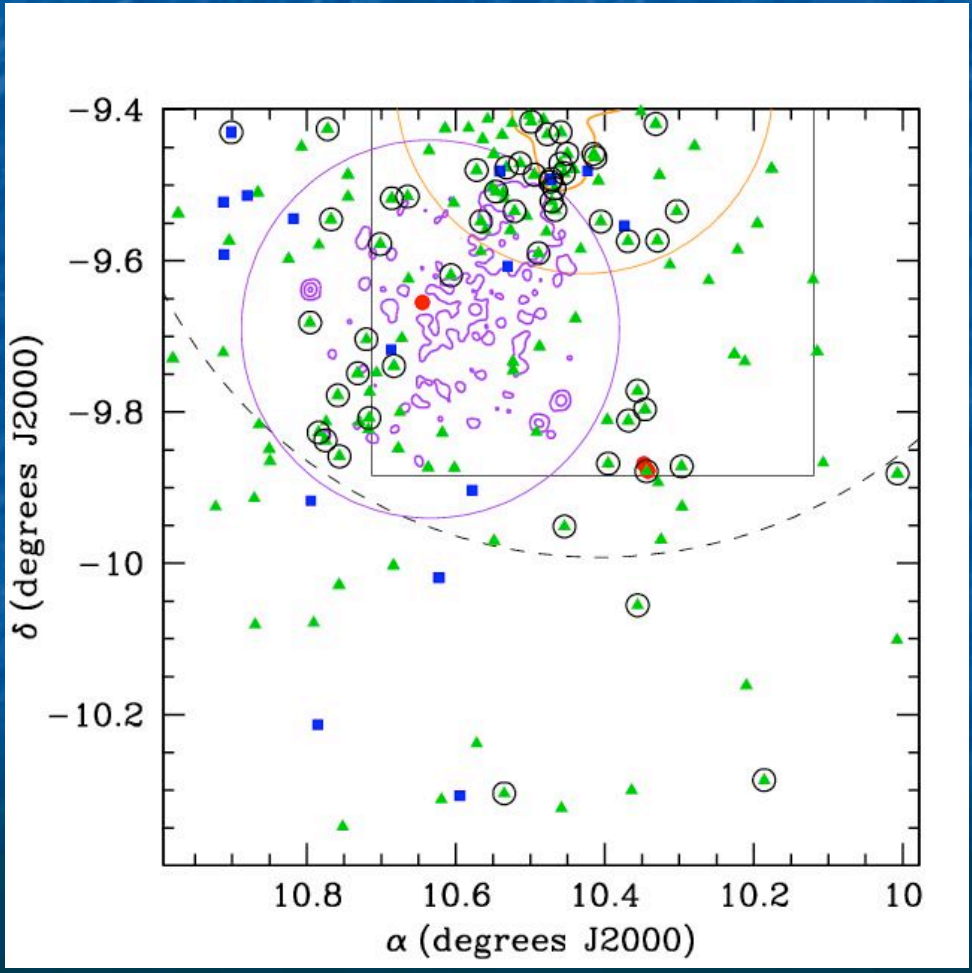
  $z_{phot} > 0.4$ but a few may be in the filament

Spatial distribution of the galaxies detected in Halpha



- Blue circles = Halpha detections in the cluster
- O Black circles=SDSS spectrum with Ha
- ❑ Red squares=Ha detections, only zphot
- X Green crosses=Ha detections, no zphot

The filament is probably a dynamically bound structure



Serna & Gerbal (1996, A&A 309, 65) method suggests galaxies circled in black are dynamically bound

- Filled red circles=ellipticals
- Filled green triangles=intermediate spirals
- Blue squares=late type spirals

Conclusions

- Optical data agree with the hypothesis that the filament discovered in X-rays is also a region with a galaxy overdensity
- There may be an excess of Halpha emitting galaxies in the filament (and in the impact region), suggesting higher star formation rates
- These results confirm that the filament is most probably made of groups falling on to the main Abell 85 cluster

Lunch time!

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